



ANALYSIS AND IMPLEMENTATION OF D-SSVR FOR LOAD FLOW SOLUTION IN RADIAL DISTRIBUTION SYSTEMS

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ABSTRACT

In this paper, optimal location of Static Series Voltage Regulator (SSVR), a member of D-FACTS devices family, for voltage improvement and loss reduction in distribution system, is implemented. A simple and modified method for node and line identification used in load flow calculations for solving radial distribution network is presented. In order to minimize line losses of power systems, it is crucially important to define the location of SSVR to be placed in the given distribution system. D-SSVR is a distribution static Series voltage regulator, which corrects the voltage magnitude at the load end irrespective of voltage disturbances at the source. The proposed method is successfully applied to the IEEE-15 bus and IEEE-29 bus distribution systems.

INTRODUCTION

The modern power distribution network is constantly being faced with an ever-growing load demand. Distribution networks experience distinct change from a low to high load level every day. Electric load growth and higher regional power transfers in a largely interconnected network becoming more complex and less secure power system operation. Power generation and transmission facilities are unable to meet these new demands. Electrical power losses in distribution systems correspond to about 70% of total losses in electric power systems. These electrical losses can be considerably reduced through the installation and control of reactive support equipments, such as capacitor banks, reducing reactive currents in distribution feeders and so on. One of the most severe problems faced by distribution networks operators is voltage drop along distribution feeders, which is caused by real and reactive power flow. Voltage control is a difficult task because voltages are strongly influenced by random load fluctuations. Voltage profile can be improved and power losses can be considerably reduced by installing Power Devices or Controllers at suitable location. These controllers which are also named Distribution Flexible AC Transmission System (D-FACTS) and are a new generation of power electronics-based equipment aimed at enhancing the reliability and quality of power flows in low-voltage distribution networks. Among the various power devices, Distributed Static Series Voltage Regulator (D-SSVR) is considered in this paper which is a modified form of DVR and the method for modeling D-SSVR is considered in modified load flow computations. Further the optimal location is identified to place D-SSVR for the purpose of loss reduction and voltage improvement.

D-FACTS Devices: Deregulation of electricity that is taking place will affect all business aspects of power industry as known from generation, to transmission, distribution and consumption. With deregulation, the need for better control strategy to maintain the level of reliability is essential. Flexible AC Transmission System (FACTS), and FACTS controllers, which are power electronic devices used to control the power flow and enhance the stability, have become common words in the power industry and they started replacing the mechanically controlled devices. They have a major role in operation and control of today's power system. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), the possibility has arisen in using different types of controllers for efficient shunt and series compensation. It should be noted that FACTS devices respond quickly to the changes in network condition. The concept of FACTS devices was originally developed for transmission systems, but similar idea has been started to be applied in distribution systems. All D-FACTS devices are capable of providing a number of power quality functions which can be employed selectively or simultaneously. In general facts controllers can be divided in to four categories:



- Series FACTS controllers
- Shunt FACTS controllers
- Combined series – series FACTS controllers
- Combined series – shunt FACTS controllers

Distribution FACTS Controllers:

Distribution Power Devices is classified into three categories by their structures such as Dynamic Voltage Restorer (DVR), Distributed SSVR (D-SSVR) and Solid-State Breaker (SSB). Among these devices, D-SSVR and the DVR share a similar architecture and both are based on the voltage source converter. DVR and DSSVR are connected in series with the line.

Proposed Distributed SSVR:

Distribution Static series voltage regulator (D-SSVR), is utilized to compensate power quality problems and also it can quickly regulate its susceptance to provide dynamic reactive compensation and regulate the bus voltages in the power system. The D-SSVR is a series-connected, solid-state switching power converter that provides flexible voltage control at the point of connection to the utility distribution feeder for power quality (PQ) improvements such as unbalanced load, voltage sag, voltage fluctuation and voltage unbalance and also exchanges both active and reactive power (voltage) with the distribution system by varying the amplitude and phase angle of the converter. A voltage-source converter is a power electronic device, which can generate sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. D-SSVR belongs to the series voltage controller.

Structure of D-SSVR:

D-SSVR, which is schematically shown in below figure consists of energy storage device, voltage source converter, a coupling transformer connected in series to the distribution network through a coupling transformer.

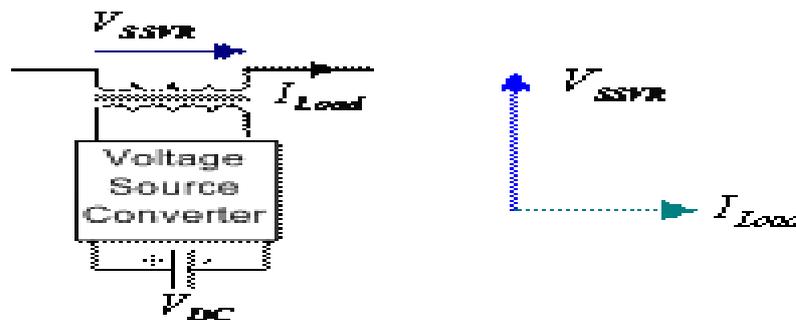


Figure-1: A typical model of SSVR and Phasor diagram of reactive power exchange

In this model, D-SSVR is capable of injecting active power in addition to reactive power. Since this device is utilized in steady-state condition for long term, because of limited capacity of energy storage system, it cannot inject active power to the system for long term for voltage regulation purpose. Therefore, for the steady-state application, D-SSVR consists of a small DC capacitor and a voltage source converter and the steady-state power exchange between D-SSVR and the ac system is reactive power. The VSC connected in series with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

- Voltage regulation and compensation of reactive power
- Correction of power factor
- Elimination of current harmonics

**Operation of D-SSVR:**

D-SSVR is to suppress voltage variation and control reactive power in phase with system voltage. It can compensate for inductive and capacitive currents linearly and continuously. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-SSVR output voltages allows effective control of active and reactive power exchanges between the D-SSVR and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The real power exchanges between the inverter and the AC system can be controlled by altering the phase angles between the inverter output and the AC system voltages. The inverter supplies real power to the AC system if the inverter output voltage is made to lead the corresponding AC system voltage. Conversely, the inverter absorbs real power from the AC system, if the inverter output voltage is made to lag the AC system voltage. There are two techniques for controlling the SSVR. The first technique, referred to as phase control, is to control the phase shift to control the SSVR output voltage magnitude. The other technique referred to as Pulse Width Modulation (PWM), allow for independent control of output voltage magnitude and phase shift (phase angle of the output voltage); in this case, the DC voltage is controlled separately from the AC output voltage.

Radial Distribution System Load Flow Method:

Load flow is a very important and fundamental tool for the analysis of any power system and is used in operational as well as planning stages. Load flow analysis of distribution system has not received much attention unlike load flow analysis of transmission systems. However some work has been carried out on the load flow analysis of distribution network. Generally, distribution networks are radial and the R/X ratio is very high compared to a transmission system. This makes the distribution system ill-conditioned. That is why the conventional load flow method such as Newton-Raphson, (NR) and the Fast Decoupled Load Flow (FDLF) method and their modification are not suitable for solving the load flow problem of such an ill-conditioned system. For most of the cases NR and FDLF methods failed to converge in solving the load flow problem of distribution system or converged in high iterations. Distribution Power Flow is an important tool for the analysis of distribution system and it is used in the operational as well as in planning stages. The distribution load flow method is used to calculate the voltage at each bus and total real and reactive power losses.

Consider a single line diagram of two buses of a radial distribution system as shown in Figure-2. Let the number of branches be “nb”, the number of buses “t” and are related through, $t = nb + 1$.

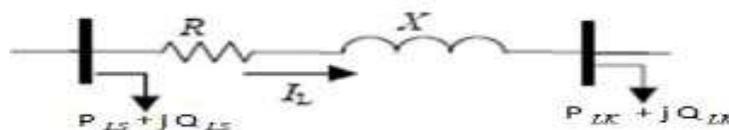


Figure 2: Single line diagram of two buses of a distribution system

Where “R” and “X” are resistance and reactance of the branch. “P_{Lk}” and “Q_{Lk}” are the active and reactive powers of node k. “I_L” is the current flowing in the line. Subscript ‘L’ in “P_{LS}” and “Q_{LS}” refers to the load connected at Sth bus. Initially, a flat voltage (1 p.u) at all the nodes is assumed and load currents and charging currents of all the loads are computed using eqns. (1) and (2).

The load current of node k is given by

$$I_{Lk}(k) = \frac{P_{Lk}(k) - jQ_{Lk}(k)}{V^*(k)} \quad \text{for } k = 2, 3, \dots, nb \quad (1)$$

The charging current at node k is given by

$$I_{Ck}(k) = y_0(k) * V(k) \quad \text{for } k = 2, 3, \dots, nb \quad (2)$$

Branch Current “I(n)” is equal to the sum of the load currents of all the nodes beyond that branch ‘n’ plus the sum of the charging currents of all the nodes beyond that branch ‘n’.



$$\text{i.e., } I(n) = \sum_{k=n+1}^{nb} I_{Lk}(k) + \sum_{i=n+1}^{nb} I_{Ck}(k) \quad (3)$$

Where branch impedance is given by $Z = R + jX$. Therefore, if it is possible to identify the nodes beyond all the branches, it is possible to compute all the branch currents.

A generalized equation of receiving-end voltage, sending-end voltage, branch current and branch impedance is given by $V(a_2) = V(a_1) - I(i) * Z(i)$ (4)

Where "i" is the branch number

$a_1 = RE(i)$ and $a_2 = SE(i)$ and $RE(i)$ is the receiving end, $SE(i)$ is the sending end of branch i.

The real and reactive power loss of branch "i" are given

$$\begin{aligned} L_{\text{real}}(i) &= |I(i)|^2 * R(i) \text{ and} \\ L_{\text{reactive}}(i) &= |I(i)|^2 * X(i) \end{aligned} \quad (5)$$

The load flow method of radial distribution network can be solved in three sets of operations:

- Identification of the nodes beyond all the branches.
- Determination of branch currents.
- Determination of the nodal voltages.

Identification of the nodes beyond all the branches:

By using below algorithm we can find the identification of nodes beyond all branches

- Step 1 : read the system data.
 Step 2 : $i = 1$
 Step 3 : $k = i + 1$, set $i_p = 0$
 Step 4 : $nc = 0$; If $\{RE(i) = SE(k)\}$ and $\{i_p = 0\}$
 go to step 10; Otherwise go to step 12
 Step 5 : if $\{i_p = 0\}$ go to step 10;
 Otherwise go to step 6
 Step 6 : $it = 1$
 Step 7 : if $\{RE(i) = ie(i, i_p + 1)\}$ then $nc = 1$
 Otherwise go to step 8;
 Step 8 : $it = it + 1$
 If $\{it \leq i_p\}$ go to step 7;
 Otherwise go to step 9
 Step 9 : if $\{nc = 1\}$ go to step 12;
 Otherwise go to step 11
 Step 10 : $ie(i, i_p + 1) = RE(i)$
 Step 11 : $i_p = i_p + 1$;
 $IN(i_p) = 1$;
 $ie(i, i_p + 1) = RE(i)$
 $N(i) = i_p + 1$
 Step 12 : $s = s + 1$; if $\{s \leq nb\}$ go to step 6;
 Otherwise go to step 13
 Step 13 : if $\{i_p = 0\}$; go to step 14;
 Otherwise go to step 15
 Step 14 : $ie(i, i_p + 1) = RE(i)$;
 $N(i) = i_p + 1$; go to step 15
 Step 15 : $i = i + 1$; If $\{i \leq nb - 1\}$ go to step 3;
 Otherwise go to step 16
 Step 16 : $ie(nb, 1) = RE(nb)$; $N(nb) = 1$
 Step 17 : Stop



Determination of branch currents:

The load current and charging current of each node are calculated by using equations (1) and (2) and identification of nodes are determined. Then it is easy to calculate the branch current is given by

$$I(i) = \sum_{k=1}^{nb} IL\{ie(i, k)\} + \sum_{k=1}^{nb} IC\{ie(i, k)\} \tag{6}$$

Determination of the nodal voltages:

To determine the voltage at each node in radial distribution network, the modified load flow method is used and the algorithm is as follows.

- Step 1 : Read the line and load data.
- Step 2 : Determine the nodes beyond each branch and their total number.
- Step 3 : Initialize the voltage of all nodes to 1p.u and phase angle to zero.
- Step 4 : Find all load currents and charging currents of each nodes using Equations (1) and (2) by using these, branch currents are determined given in Equation (3).
- Step 5 : Calculate the voltages and phase angles at each node by using Equation (4).
- Step 6 : If the voltage at each node for two successive iteration is within a certain tolerance (10^{-4} p.u) the solution is reached go to step 8 else, repeat step 5 to 7 until convergence is reached.
- Step 7 : Read the results

PROPOSED METHODOLOGY

In this paper, a modified load-flow technique implementing D-SSVR is considered for solving radial distribution networks. The proposed method involves only the evaluation of a simple algebraic expression of receiving-end voltages. The proposed method can be used to find out the voltages of nodes, D-SSVR voltage, phase angle and injected reactive power by SSVR. These are used to determine the load currents in the proposed load flow method, and power losses. A single-phase equivalent circuit of two buses of a distribution system and its phasor diagram after installing D-SSVR are shown in Figures-3 and 4 respectively. Generally, voltage of buses in the system is less than 1 p.u. and it is desired to compensate voltage of interested bus (V_s) to 1 p.u. by using D-SSVR.

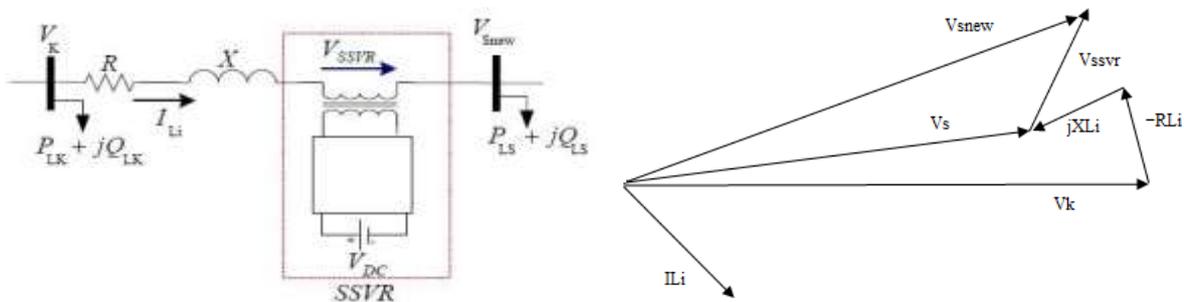


Figure 3: Single line diagram of two buses of a distribution System with D-SSVR and its phasor diagram

The injected reactive power by SSVR can be written as

$$jQ_{SSVR} = V_{SSVR} * I_{Li} \tag{7}$$



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By installing Static series voltage regulator (SSVR), in distribution system, all nodes voltage, especially the neighboring nodes of SSVR location, and branches current of the network, change in the steady-state condition.

SSVR is used to suppress voltage variations and control reactive power in phase with system voltage. It can compensate for inductive and capacitive currents linearly and continuously.

The following algorithm describes implementation for modeling of D-SSVR in modified load flow method to determine the voltages at each node, real and reactive power losses in radial distribution network.

Algorithm with D-SSVR:

- Step 1 : Read the line and load data.
- Step 2 : Determine the voltages and losses by using modified load flow method without installing D-SSVR.
- Step 3 : Install SSVR and it is desired to compensate voltage of interested bus (V_s) to 1 p.u. and find out injected reactive power, phase angle and D-SSVR current (I_{D-stat}) by using Phasor diagram method given in eqn. (3.21), eqn. (3.20) and eqn. (3.23) respectively
- Step 4 : Determine voltages by using Eqn. (3.9) and run modified load flow method again.
- Step 5 : Then repeat step.2 and again place D-SSVR at another location and similarly repeat step.3 and 4 to find at all nodes and find out losses.
- Step 6 : Read the results and find out the node at which minimum losses are obtained and it is selected for optimum location for D-SSVR.

In this modified load flow method line charging capacitance is also taken into account in the above algorithm which is actually neglected in the load flow method presented.

RESULTS AND DISCUSSION

In this paper, software program has been developed in MATLAB for simple and modified load flow method and optimal location of D-SSVR on radial distribution system. This MATLAB program is tested for two systems viz., IEEE-15 bus and IEEE-29 bus systems.

The Load Flow Results of 15-bus system:

Table-1: Voltages of the system after running the load flow

Node No.	Voltage Magnitudes in p.u before installing D-SSVR	Voltage Magnitudes after compensation in p.u at 14 th -node
1	1.0000	1.0000
2	0.9720	0.9793
3	0.9574	0.9704
4	0.9516	0.9679
5	0.9506	0.9652
6	0.9589	0.9707
7	0.9567	0.9698
8	0.9576	0.9697
9	0.9685	0.9749
10	0.9673	0.9719
11	0.9506	0.9669
12	0.9463	0.9639
13	0.9449	0.9623
14	0.9493	1.0594

**Table-2: Real and Reactive power losses of 15 – bus distribution system after installing the D-SSVR**

Node No.	Real power losses (KW)	Reactive power losses (KVAR)
2	46.3284	43.1650
3	51.2095	47.9466
4	46.7527	43.8373
5	45.0766	42.5469
6	46.6060	43.9625
7	50.7457	47.6998
8	46.8227	47.6950
9	46.5731	43.7981
10	47.9420	44.9010
11	52.0156	48.7706
12	49.8216	46.7485
13	40.6550	37.8458
14	32.5829	29.7603

Without D-SSVR, and running load flow method the total real and reactive power loss of this system are **60.0628 KW** and **55.5749 KVAR** respectively. The minimum losses are obtained i.e., **32.5829KW** and **29.7603KVAR** of real and reactive power losses respectively, when the device is placed at node-14.

Load flow Results for 29-bus system:**Table-3: Voltages of the system before and after installing D-SSVR**

Node No.	Voltage Magnitudes in p.u before installing D-SSVR	Voltage Magnitudes in p.u after installing D-SSVR
1	1.0000	1.0000
2	0.9797	0.9973
3	0.9603	0.9954
4	0.9505	0.9942
5	0.9444	0.9932
6	0.9228	0.9901
7	0.9100	0.9875
8	0.9041	0.9861
9	0.8946	0.9837
10	0.8837	0.9801
11	0.8755	0.9779
12	0.8720	0.9768
13	0.8635	0.9730
14	0.8563	1.0000
15	0.8524	0.8524
16	0.8504	0.8501
17	0.8477	0.8475
18	0.8470	0.8456
19	0.9603	0.9949
20	0.9592	0.9942
21	0.9577	0.9928
22	0.9565	0.9909
23	0.9505	0.9937
24	0.9484	0.9922



25	0.9464	0.9890
26	0.9100	0.9890
27	0.9094	0.9885
28	0.9091	0.9879

Table-4: Real and Reactive power losses of 29 – bus distribution system after installing the D-SSVR at each node

Node No.	Real power losses (KW)	Reactive power losses (KVAR)	Node No.	Real power losses (KW)	Reactive power losses (KVAR)
2	223.7781	89.6930	16	246.8319	99.0341
3	217.3539	87.0042	17	180.5158	73.3967
4	220.8610	88.4823	18	229.8180	92.3106
5	235.4478	94.5879	19	229.3951	92.1527
6	197.6378	78.7914	20	235.3838	94.5248
7	201.3702	80.3570	21	228.1993	91.6744
8	235.1123	94.4421	22	231.8306	93.1107
9	191.3884	76.1947	23	226.4149	90.8675
10	195.4417	78.2509	24	222.1054	89.0657
11	185.1072	74.1731	25	251.2081	101.1378
12	209.5161	84.2813	26	215.2914	86.1978
13	223.8310	90.0338	27	241.4409	97.2383
14	177.2625	72.0702	28	232.8760	93.5262
15	205.5834	83.0338			

When the proposed load flow method is executed without D-SSVR, the total real and reactive power loss of this system are **303.927 KW** and **122.3292 KVAR** respectively. The minimum losses are obtained i.e., **177.2625 KW** and **72.0702 KVAR** of real and reactive power losses respectively, when the device is placed at node-14. Thus D-SSVR improves the voltage of both nearby downstream nodes and nearby upstream nodes, especially the nodes located between D-SSVR and the source.

CONCLUSION

A simple and modified load-flow technique has been proposed for solving radial distribution networks. The method has good and fast convergence characteristics compared with some other existing methods. Later Static series voltage regulator (SSVR) is applied to proposed load flow calculations in 15- and 29-bus IEEE test systems. The optimum location for SSVR is identified based on minimum losses. The results indicate that the proposed model can be applied for large distribution systems.

FUTURE SCOPE

The proposed method can be extended for a system with large number of buses and with multiple FACTS devices. Modeling of SSVR can be determined with the fuzzy sets for better results, as mathematical modeling is not necessary in fuzzy logic.

REFERENCES

1. Haque M. H., Capacitor placement in radial distribution systems for loss reduction, IEE Proc. Gener. Transm. Distrib., 1999, 146(5), p. 641-648.
2. Haque M. H., Efficient load flow method for distribution systems with radial or meshed configuration, IEE Proc. Gener. Transm. Distrib., 1996, 143(1), p. 33-38.
3. Jin M. A., Jianyuan X. U., Shenghui W. and XIN L, Calculation and analysis for line losses in distribution network, IEEE International Conference on Power system Technology, pp. 2537-2541, 2002.
4. D.Das, H.S.Nagi, D.P.Kothari, "Novel method for radial distribution networks", IEE Proc.-Gener. Transm. Distrib., Vol. 141, No. 4, July 1994.



Global Journal of Engineering Science and Research Management

5. KERSTING, W.H.: 'A method to teach the design and operation of a distribution system', IEEE Trans., 1984, PAS-103, pp. 1945-1952
6. IWAMOTO, S., and TAMURA, Y.: 'A load flow calculation method for ill-conditioned power systems', IEEE Trans., 1981, PAS-100, 1736-1713.
7. BARAN, M.E., and WU, F.F.: 'Optimal sizing of capacitors placed on a radial distribution system', IEEE Trans., 1989, PWRD-2, pp. 735-743.
8. N. E. Chang, " Locating Shunt Capacitors on Primary Feeder for Voltage Control and Loss Reduction," presented at the IEEE Trans. (Power Apparatus and Systems),. vol. pas-88, no. 10, October 1969.
9. J. V. Schmill, "Optimum size and location of shunt capacitors on distribution feeders," IEEE Trans. Power Apparatus and Systems, vol. 84, pp. 825-832, September 1965
10. TINNY, W.F., and HART, C.E.: 'Power flow solution by Newton's method', IEEE Tram., 1967, PAS86, pp. 1449-1456
11. JASMON, G.B., and LEE, L.H.C.C.: 'Distribution network reduction for voltage stability analysis and load flow calculations', Electr. Power Energy Syst., 1991, 13, pp. 9-13.
12. JASMON. G.B. and LEE. L.H.C.C.: 'Stability of load flow techniques for distribution system voltage stability analysis', IEE Proc. C, 1991, 138, (6), pp. 479-484.
13. Baran M. E., WU F. F., Network reconfiguration in distribution systems for loss reduction and load balancing, IEEE Transactions on Power Delivery, 1989, 4(2), p. 1401-1407.
14. Baran M. E., Wu F. F., Optimal capacitor placement on radial distribution systems, IEEE Transactions on Power Delivery, 1989, 4(1), p. 725-732.